



## Expanding Boundaries: Systems Thinking for the Built Environment

### LOW CARBON CEMENT: A SUSTAINABLE WAY TO MEET GROWING DEMAND IN CUBA

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#### Abstract

Concrete is, after water, the most used material worldwide and its demand is projected to growth in the next 30 years. Among all concrete materials, cement presents the higher energy consumption and carbon emissions, that's why this industry has been developing several alternatives to gain sustainability. The reduction of the clinker ratio by using Supplementary Cementitious Materials (SCM) allows a better use of existing capacities with low investment while a reduction in emissions, costs and energy per ton of cement is observed. The objective of this article is to assess the environmental and economic impact of a new cement with 50% of clinker: Low carbon cement (LC<sup>3</sup>). A procedure for evaluating sustainable and economic contributions of LC<sup>3</sup>, while projected demand is satisfied, is designed and applied in several scenarios. The results demonstrate that the introduction of LC<sup>3</sup> is the best option to meet growing demand considering capital investment options in non-developed countries conditions with a reduction of ~30% in carbon emissions, of ~10% in costs and a faster return of investments related to OPC figures in Cuba.

#### Keywords:

Low Carbon Cement; cement demand; economic and environmental assessment

### 1 INTRODUCTION

Cement is a key resource for economic progress and development. Consequently, global demand for cement and concrete has increased exponentially in the last twenty years as well as its related environmental impact. Due to this situation, the cement industry has applied several strategies to improve its production efficiency and to reduce both resources consumption and carbon emissions. One of the most effective solutions is the use of supplementary cementitious materials (SCM) [1-2].

Low Carbon Cement (LC<sup>3</sup>) has emerged as new alternative cement as a result of an international joint project funded by the Swiss Agency for Development and Cooperation with the

participation of scientists from Switzerland, Cuba and India. In LC<sup>3</sup> cement, it is replaced by up to 50% of clinker in cement by using calcined clay and limestone.

The Cuban economy is currently experiencing large structural changes. The Cuban government has declared an expected – and needed – annual Gross Domestic Product (GDP) growth from 3 to 5% [3]. To achieve this, the construction sector has to reach a level of production able to satisfy the development demands. In this paper, a method is designed and applied to assess the economic and environmental potential of the LC<sup>3</sup> cement technology in several scenarios of the Cuban context, while projected demand is satisfied.

## 2 DATA AND METHODS

### 2.1 Methodology

To assess the economic and environmental contribution of LC<sup>3</sup> production, the following methodologies are integrated and applied:

- (i) Forecast of cement demand
- (ii) Life cycle assessment (LCA)
- (iii) Capital expenditures (CAPEX) and Operational expenditures (OPEX) analysis

To forecast demand is a major issue in this study in order to estimate the investment needs to reach development. Demand for Cuba, cement demand was calculated using a model based on possible needs of cement according to social and economic infrastructure status and government plans for investments.

The environmental evaluation is done through a Life Cycle Assessment (LCA). It is a method for evaluating the environmental load of processes and products during their life cycle, from cradle to grave [4]. The LCA method is divided into 3 main stages [4]. First, the functional unit and the system boundaries have to be defined. Secondly, the inventory phase includes all inputs to outputs from the considered system. Finally, the environmental impact categories are defined and assessed. These three stages are detailed in the following section.

Capital and Operational Expenditures analysis are performed to assess and compare the economic impact of cements during their life cycle from investment process (CAPEX) until cement is produced. CAPEX were calculated based on literature and OPEX by using accounting norms established in Cuba. To a better understanding all costs were converted to US dollars.

### 2.2 Choice of the functional unit

This study focusses on the production and transport of the cement raw materials and ends at an intermediate stage after concluding the production process at the cement plant (cradle to gate). The functional unit used in the study is 1 ton of cement.

The study compares three cements production in Cuba:

- (1) The standard Ordinary Portland Cement (OPC). This cement in Cuba is made with 5% of Calcium Carbonate.
- (2) The current blended cement sold on the island (PPC). It is produced with 15% of Zeolite tuff considered as a Natural Pozzolan.
- (3) The new cement, called Limestone Calcined Clay cement (LC<sup>3</sup>) where 30% of Calcined Clay and 15% of Calcium Carbonate.

Previous studies provided confidence in the fact that similar compressive strength can be

achieved with these 3 cements [5] what was confirmed in the first industrial trial to produce LC<sup>3</sup> [6].

The production system under study has been separated into five main processes: (i) raw materials extraction; (ii) extraction and refinement of fuels; (iii) transport of raw materials and fuels; (iv) clinkerization and calcination of clays; and (v) grinding, packing and other processes. The final processes are gathered due to their low impact during the whole process of cement production [7].

The determination of same functional unit and system boundaries for economic and environmental assessment allows the integrated assessment after obtaining separately results.

### 2.3 Data collection

In this study the data is organized according to the technological level to be implemented reflecting a gradation in the investment.

- (i) The first level (Pilot) considers no investment. The data used for energy and material consumption were measured during the first industrial trial [6]. The clinkerization as well as the clay calcination were carried out at existing facilities within an inefficient and non-optimized production processes (wet process).
- (ii) The second technological level considers a low investment throughout retrofitting a wet cement kiln into a clay calciner, as a low CAPEX alternative to produce calcined clay. The clinker employed is produced by a more efficient technology (dry process).
- (iii) The third technological level considers massive investment in Best Available Technology (BAT), with state of the art equipment for both the calcined clay and the clinker production. Clay would then be calcined through a flash calciner and clinker would be produced by a dry process with pre heater and pre calciner.

Once these technological packages were established, the necessary data was collected. Data for emission factors and heating values of different types of fuels comes from different sources: (i) the Cement Sustainability Initiative (CSI) of the World Business Council for Sustainable Development [8] and (ii) the Intergovernmental Panel for Climate Change (IPCC) [9]. Some processes linked to the extraction of raw material and fuels, transport and electricity were modelled using the Ecoinvent database [10] and adapted when necessary to the Cuban conditions. The electricity mix, the fuel used for trucks and trains and lifetime of the current stock of Cuban transport infrastructure were adapted.

Preliminary data was collected from the Siguaney factory which has been selected by the Cuban Cement industry to introduce LC<sup>3</sup> production. The main data is related to consumption indexes, distances to raw materials, technology type, transport means and extraction processes.

To analyse CAPEX figures, data related with different investment scenarios was collected. The data is shown in Figure 1, where a simple comparison allows to prove the advantages of retrofitting over investing in a flash calciner.

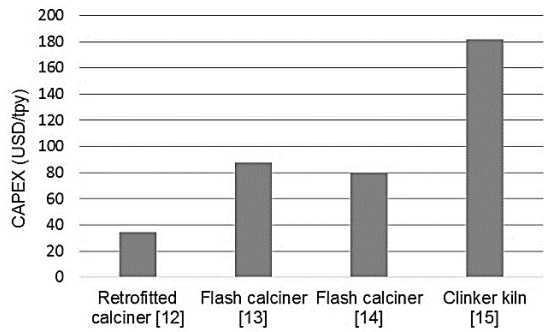


Fig. 1: CAPEX (US dollars per ton of cement per year) and references.

## 2.4 Impact assessment

In this study, only one impact category is shown: Global Warming Potential for one-hundred-year period of time projection (GWP100) expressed in kg CO<sub>2</sub> equivalent. It was calculated by the IPCC 2013 methodology [9]. This reduction is justified by the fact that CO<sub>2</sub> emission is the main impact of concrete industry and it is difficult to look for the large number of background and foreground data required for the other impact categories in Cuban statistics reports.

## 3 RESULTS

### 3.1 Demand forecast for Cuban case

Cuban cement industry reports production of 1.8million tons of cement in 2014 [15], this represents a 56% of utilization of the installed capacity. A higher utilization rate is not possible due to several periods of maintenance and reparation of equipment and facilities associated with the existing outdated technology. Then, a 68% of the available production capacity is determined. This proves the fact that present demand exceeds production and reflects the need for investment in this sector to increase manufacturing capacity.

Official government figures forecast cement demand of 3.5Mt/year by 2019. Demand

projection at peak demand phase (2016-2020) will grow 18% per year. This is linked to an expected booming construction activity that normally occurs in emerging economies. During the peak demand phase annual growth of 10% and 5% of demand are expected. Finally, authors estimate a capacity over 6.5 million tons/year to be reached in 2030.

### 3.2 Comparative Life cycle assessment of LC<sup>3</sup> and other products in Cuban case

#### Energy consumption

Results of a detailed analysis of the improvement potential of LC<sup>3</sup> production in relation to energy use show that the best improvement is observed in clinkerization and fuels extraction processes when compare with OPC production. An increase in energy consumption related to transport and raw materials extraction is also observed but this impact is clearly negligible when it is compared with savings achieved by the other processes. A reduction of ~20% in energy demand is achieved when compare with OPC, except using the BAT (which includes the use of renewable fuels) where 8% of energy is saved if LC<sup>3</sup> is produced. Table 1 presents the final results in energy analysis.

Cement	MJ/t	%
OPC	5292	100
PPC	4626	87
LC <sup>3</sup> _retrofitted	4158	79
LC <sup>3</sup> _flash	3692	70

Table 1: Energy consumption (MJ) per ton of cement produced.

#### Environmental impact (GHG emissions)

The comparison of the environmental impact for OPC, blended cement PPC and LC<sup>3</sup> for the three different technical levels: Pilot, Industrial and BAT– is shown in the figure 3. It is interesting to note that whatever the technological level, the LC<sup>3</sup> cement always produces around 30% savings of CO<sub>2</sub> eq emissions. Furthermore, it is noticed that the worse LC<sup>3</sup> cement made in the pilot industrial trial is better than the best OPC that can be produced with the BAT scenario. Major emission reductions are related to energy savings and clinker substitution, although there is reported a significant decrease in electricity consumption during grinding process due to LC<sup>3</sup> softness in comparison with OPC.

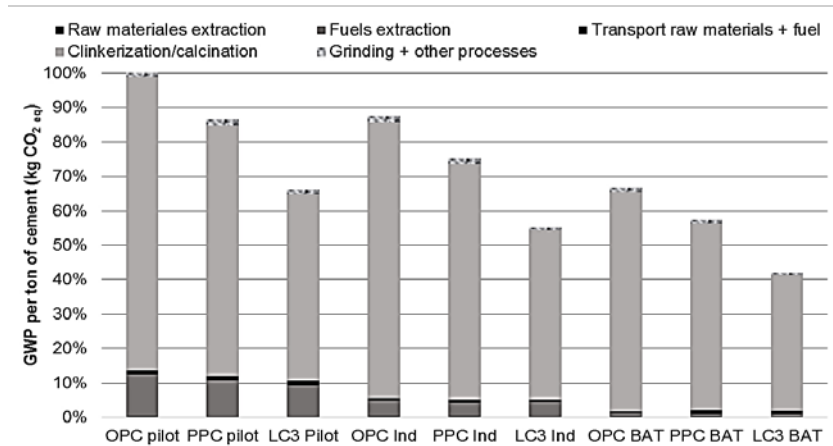


Figure 3. Relative Global Warming Potential impact of cement production in Cuba. All scenarios.

### 3.3 CAPEX and OPEX analysis

Operational expenditures were calculated in collaboration with an economic team of the Siguaney cement plant. Results confirm that with LC<sup>3</sup> production we can save 14-30% of costs in comparison with PPC and OPC respectively as shown in Figure 2.

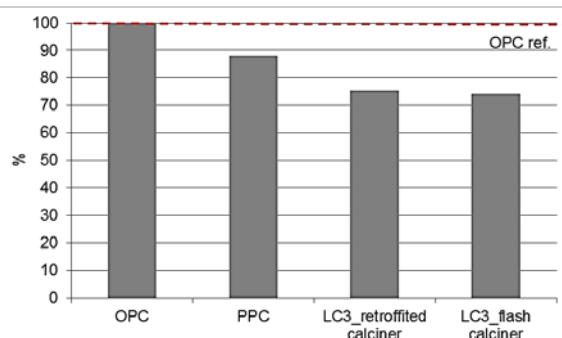


Figure 2. OPEX of cement production: comparison OPC and PPC vs. LC<sup>3</sup>.

Is notable that OPEX between flash and retrofitted are quite similar (flash is only 1% lower). This can be supported by 2 reasons: (i) CAPEX for flash is much higher; (ii) the other processes of cement production process are carried out in similar facilities, thus, costs for grinding, clinker production, packing, etc. are the same.

CAPEX figures show that the construction and installation of a clinker kiln (+ pre heater + pre calciner and cooling facilities) will always be more expensive than a clay calciner. Retrofitting is the best alternative thinking also in the lack of capital of non-developed countries like Cuba and the availability of old wet clinker kilns that can be retrofitted with low investment cost.

## 4 DISCUSSION

This assessment shows that promoting the use of LC<sup>3</sup> in Cuba is a long term efficient strategy from an environmental as well as from an economic point of view. Results show that LC<sup>3</sup> technology,

if implemented in Cuba will definitively provide an environmental advantage compared to the OPC and PPC produced on the island. The cost analysis shows also a smaller difference in comparison with PPC.

Finally, more detailed research needs to be done in the area of investment costs. The study shows the predominant contribution of investment costs (CAPEX) compared to operation costs (OPEX) in the production of cement from an economic and political point of view, but also from the availability of existing infrastructure. Then, the installation of a complete production line, will considerably increase the investment price for the LC<sup>3</sup> technology. Savings from an OPC modernization strategy will still be achieved but the difference will be smaller.

## 5 CONCLUSIONS

This study has assessed, from both an economic and environmental point of view, three cements that can be produced in Cuba. The study shows that the LC<sup>3</sup> technology, which involves the combination of 50% of clinker, 15% of unburned limestone and 30% of calcined clay (and 5% Gypsum), is an energy and cost efficient technology. Savings in term of greenhouse gases emissions as well as production and investment costs are significant.

The results presented have taken into account a number of variables and have shown to be robust. LC<sup>3</sup> has therefore a great potential to provide a viable opportunity to meet an increase in cement demand with low CO<sub>2</sub> released and low cost investment.

## 6 ACKNOWLEDGMENTS

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